Ceramic RF Power Capacitors

GENERAL DESCRIPTION

The ceramic RF power capacitor can be defined as an electrical device consisting of a ceramic dielectric with conductive noble-metal electrodes, terminations, and a protective coating. The spectrum of capacitance values extends from the lower picofarad range up to the nanofarad range. The rated voltages range from 636 V_{peak} up to 40 000 V_{peak}. Typical frequencies of application range from 20 kHz to 100 MHz. These capacitors can be operated with DC and AC voltage both individually and in combination. The electrical power-handling capacity is largely determined by the three parameters, voltage, current, and power. These parameters essentially depend on the capacitance, the operating frequency, and the ambient temperature.

APPLICATIONS

Typical uses for ceramic RF power capacitors are:

- Inductive heating equipment (operating frequencies above 20 kHz)
- Dielectric heating equipment (operating frequencies above 5 MHz)
- Impedance tuning circuits
- RF filter and pulse forming circuits
- DC voltage blocking, RF voltage dividers
- Radio transmitting equipment
- Voltage multipliers (capacitor stacks)

ELECTRICAL PARAMETERS

The electrical performance is determined by four parameters: capacitance, voltage, current, and reactive power.

CAPACITANCE

Rated capacitance C_R is the nominal capacitance value.

CAPACITANCE MEASUREMENTS

The capacitance of all ceramic RF power capacitors - except where deviations are agreed upon in the ordering procedure - are measured under the following conditions:

Measuring Frequency

Class 1 ceramic dielectric: (1 ± 0.2) MHz or (100 ± 20) kHz

Class 2 ceramic dielectric: (1 ± 0.2) kHz (field strength max. 3 kV_{RMS} per millimeter)

Measuring Voltage

Class 1 ceramic dielectric: ≤ 5.0 V_{RMS}

Class 2 ceramic dielectric: ≤ 1.2 V_{RMS}

Climatic Conditions of Measurements

Temperature: (23 ± 3) °C, for reference measurements (20 ± 1) °C
Relative humidity: ≤ 75 %

CAPACITANCE TOLERANCE

CLASS 1 - CERAMIC DIELECTRIC							
TOLERANCE	**± 0.25 pF**	**± 0.5 pF**	**± 1 pF**	**± 2 pF**	**± 5 %**	**± 10 %**	**± 20 %**
Code letter	C	D	F	G	J	K	M
Applicable nominal capacitance	< 10 pF				≥ 10 pF		

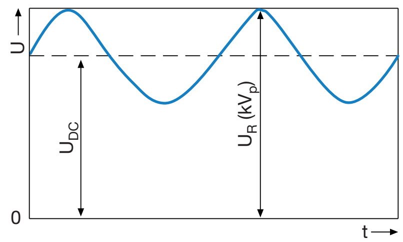
CLASS 2 - CERAMIC DIELECTRIC					
TOLERANCE	**± 5 %**	**± 10 %**	**± 20 %**	**-20 % to +50 %**	**-20 % to +80 %**
Code letter	J	K	M	S	Z

Note

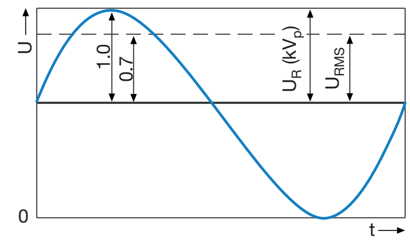
- Tolerances other than those stated in this catalog are subject to special agreement

RATED VOLTAGE

The rated voltage U_R is either the peak value of the approximate sinusoidal AC voltage or the sum of both the DC voltage and the approximate sinusoidal AC voltage for which the capacitor has been designed. The rated voltage is stated in kV_{peak} (kV_p) or V_{peak} (V_p).



DC + AC voltage



Pure RF voltage

If the capacitor is operated above the lower limit frequency f_u, the rated voltage has to be restricted so the rated power will not be exceeded (see section “Frequency”).

RATED CURRENT

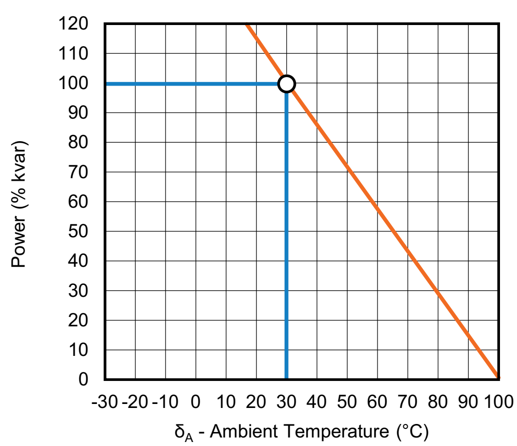
The rated current I_R is the maximum effective value of the sinusoidal current for which the current paths of the capacitor are designed. This rated current is reached only at the upper frequency limit f_o (see section “Frequency”).

RATED POWER

The rated power Q_R is the reactive power for which the capacitor has been designed taking into account its dielectric losses. The rated power Q_R (kvar) stated in the following charts refers to an ambient temperature of 30 °C. When used without forced cooling, above 30 °C, the rated power has to be reduced according to the following formula:

$$Q_N\ (\delta_A > 30\ °C) = Q_N\ (\text{catalog value}) \times \frac{100\ °C - \delta_A}{70\ °C}$$

Reactive power as a function of the ambient temperature:

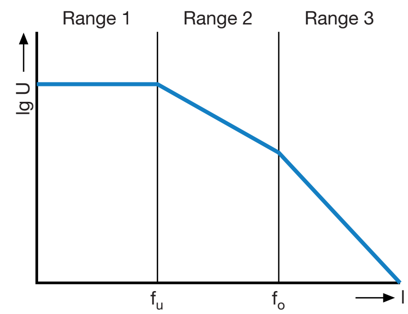


The following formula can be applied to determine whether a capacitor is operated within the permissible limits of reactive power and rated current:

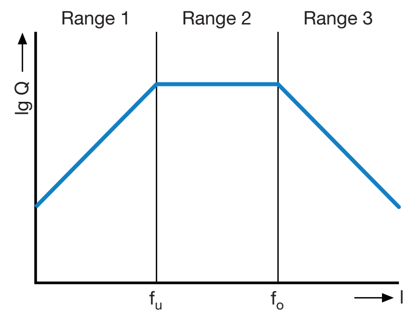
$U_{RMS} \times 2 \times \pi \times f \times C = I_R$	$U_{RMS}^2 \times 2 \times \pi \times f \times C = Q_R$	U_{RMS} in Volt f in Hertz C in Farad

FREQUENCY

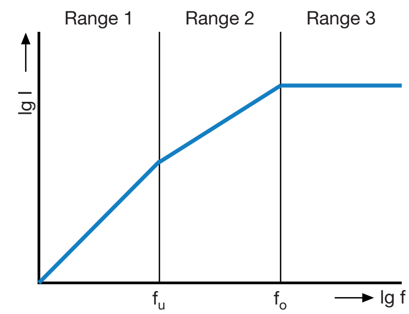
The power handling capability of a capacitor with respect to voltage, power, and current varies at different frequencies. Three frequency ranges can be defined in terms of the upper (f_o) and lower (f_u) limit frequencies. In each range one of the electrical parameters limits the maximum wattage of the capacitor.



Continuously permissible voltage in range 1



Continuously permissible voltage in range 2



Continuously permissible voltage in range 3

The limit frequencies f_u and f_o can be calculated for each capacitor with the following formula:

$f_u = \frac{318 \times Q_R}{U_R^2 \times C}$	$f_o = \frac{159 \times I_R^2}{Q_R \times C}$	f in MHz C in pF U in kVp Q in kvar I in A

For several capacitors series, this can be seen from the diagrams on the individual datasheets. For other capacitors, charts showing the maximum permissible levels of voltage, power, and current for continuous operation at 30 °C ambient temperature can be provided on request.

INSULATION RESISTANCE

The insulation resistance is the DC resistance of a capacitor, resulting under the conditions specified below, from the bulk resistivity of the dielectric material and the surface resistance. Within the range of the permissible operating temperatures, the bulk resistance of ceramic dielectric is extremely high so that mainly the surface resistance is measured.

	CLASS 1 CAPACITORS	CLASS 2 CAPACITORS
Limiting values of the insulation resistance	Min. 1 x 10^{10} Ω	Min. 5 x 10^9 Ω

INSULATION - RESISTANCE MEASURING CONDITIONS

Measuring Voltage

Class 1 and class 2 ceramic dielectric: 100 V_{DC}

Duration

(60 ± 5) s

Climatic Conditions of Measurements

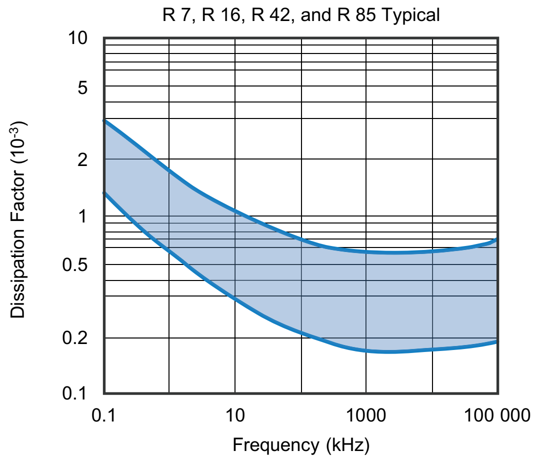
Temperature: (23 ± 3) °C, for reference measurements (20 ± 1) °C

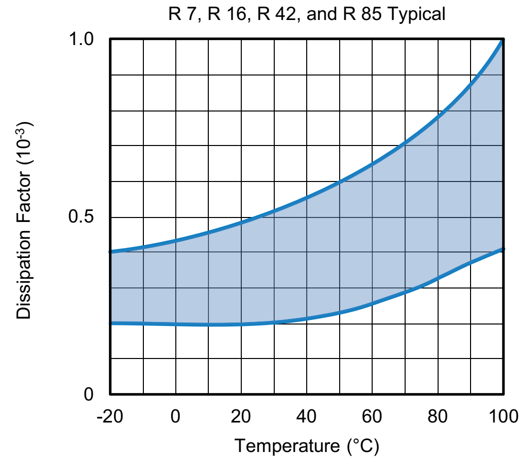
Relative humidity: ≤ 75 %

DISSIPATION FACTOR

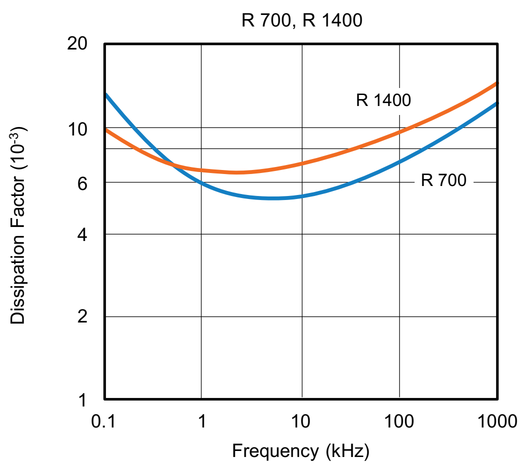
The dissipation factor tan δ is the effective to reactive ratio at a sinusoidal voltage of predetermined frequency. This ratio is dependent upon the dielectric material as well as on temperature and frequency. The curves below show the dissipation factor as a function of frequency and temperature for the preferred ceramic materials.

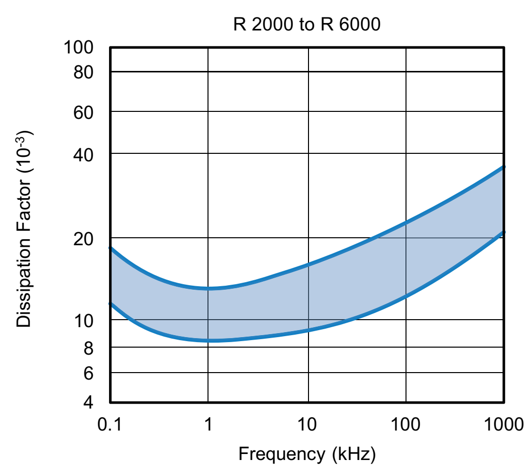
Class 1 Ceramic Dielectric

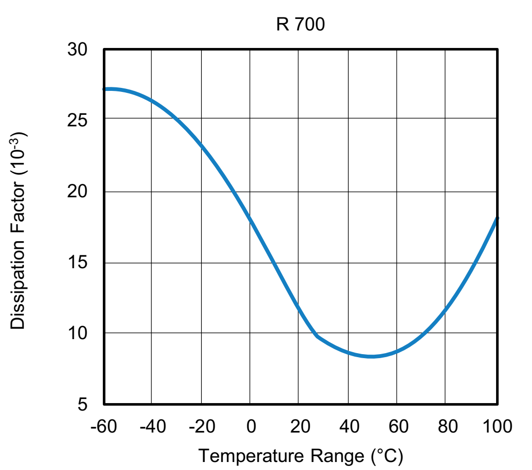


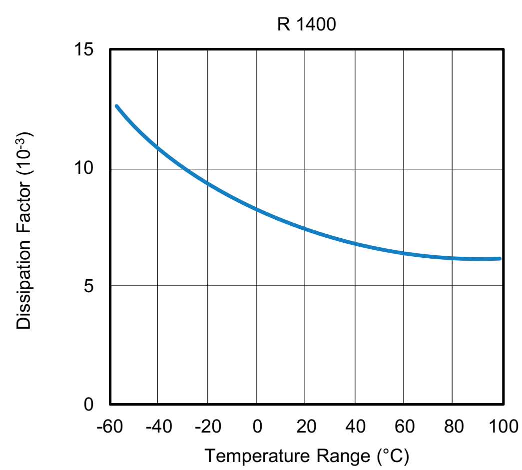


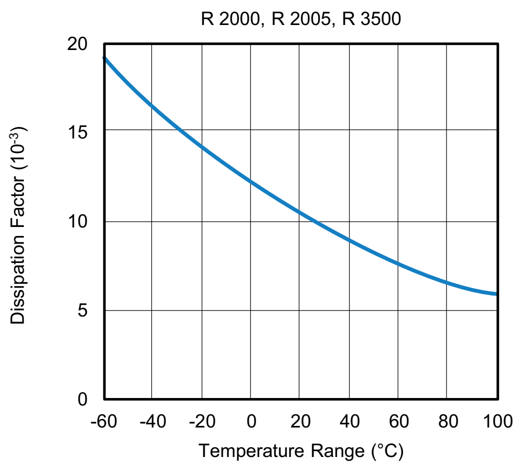
Class 2 Ceramic Dielectric

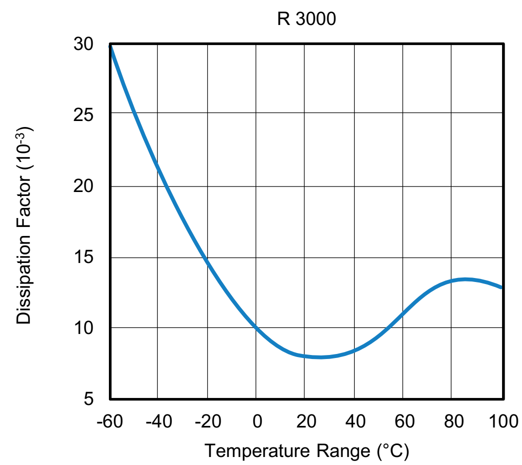


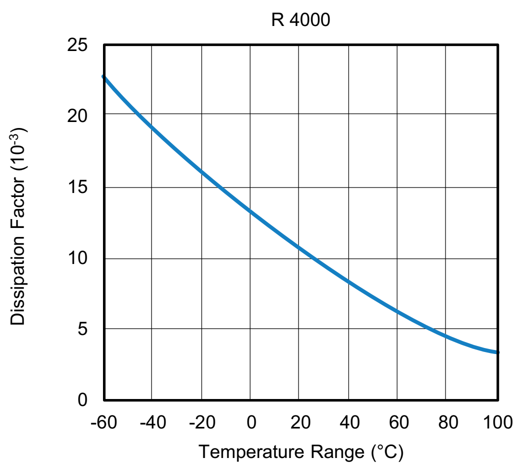


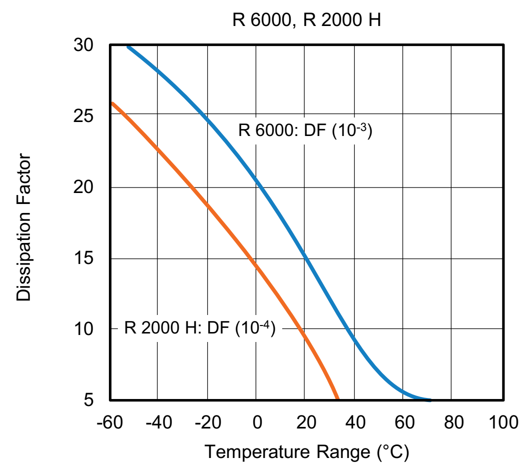












DISSIPATION FACTOR - MEASURING CONDITIONS

The dissipation factor of all ceramic RF power capacitors - except where deviations are agreed upon in the ordering procedure - are measured under the following conditions:

Measuring Frequency

Class 1 ceramic dielectric (C < 1000 pF): (1 ± 0.2) MHz or (100 ± 20) kHz

Class 1 ceramic dielectric (C ≥ 1000 pF): (300 ± 50) kHz

Class 2 ceramic dielectric: (1 ± 0.2) kHz (field strength max. 3 kV_{RMS} per millimeter)

Measuring Voltage

Class 1 ceramic dielectric: ≤ 10 V_{RMS}

Class 2 ceramic dielectric: ≤ 5 V_{RMS}

Climatic Conditions of Measurements

Temperature: (23 ± 3) °C, for reference measurements (20 ± 1) °C

Relative humidity: ≤ 75 %

CAPACITANCE "AGING" OF CERAMIC CAPACITORS

Following the final heat treatment, all class 2 ceramic capacitors reduce their capacitance value approximately according to a logarithmic law due to their special crystalline construction. This change is called "aging". If the capacitors are heat treated for example when soldering, the capacity increases again to a higher value and the aging process begins again. (Note: the level of this de-aging is dependent on the temperature and the duration of the heat; an almost complete de-aging is achieved at 150 °C in one hour: these conditions also form the basis for reference measurements when testing). The capacitance change per time decade (aging constant) differs with the various types of ceramic but typical values can be taken from the table below.

CERAMIC DIELECTRIC	R 700	R 1400	R 2000	R 2000H	R 2005	R 3500	R 4000	R 6000
Aging constant (K)	-1 %	-2 %	-2 %	-3 %	-3 %	-3 %	-4 %	-4 %

CERAMIC DIELECTRIC	X7R	Y5U	Z5U
Aging constant (K)	-3 %	-3 %	-5 %

$K = \frac{100 \text{ x } (C_{t1} - C_{t2})}{C_{t1} \text{ x } \log_{10}\frac{t_1}{t_2}}$	$C_t = C_{1000} \text{ x } \left(1 - \frac{k}{100} \text{ x } \log_{10} t\right)$	C_t = capacitance after start of aging (pF) C_{1000} = capacitance 1000 h after start of aging (pF) k = aging constant per decade (%) t = time passed since start of aging (h)

REFERENCE MEASUREMENT

Due to aging, it is necessary to quote an age for reference measurements which can be related to the capacitance with fixed tolerance. According to EN 130700, this time period is 1000 h. If the shelf-life of the capacitor is known, the capacitance for t = 1000 h can be calculated with the aging constant. In order to avoid the influence of the aging, it is important to de-age the capacitors before stress-testing.

The following protection is adopted (see also EN 130700):

De-aging at 150 °C, 1 h
Storage for 24 h at normal climate temperature
Initial measurement
Stress
De-aging at 150 °C, 1 h
Storage for 24 h at normal climate temperature
Final measurement

OPERATION CONDITIONS

The user should ensure that the permissible operating conditions are not exceeded. Concerning the applied maximum voltage the following subjects should be taken in consideration.

- Harmonic modulation and parasitic frequencies
- Transient over-voltages
- Differences in capacitance and distribution of power when capacitors connected in series
- Asymmetric HF fields

Concerning over-heating, the following subjects should be taken into consideration:

- Ambient temperature and radiation from other heat sources
- Differences in capacitance and distribution of power when capacitors connected in series
- RF induction fields and parasitic currents
- Humidity, condensation, moisture deposit

MOUNTING

The user should take care in the mechanical mounting to ensure that mechanical and thermal stresses are minimized. The connection to one electrode must be flexible in order to prevent the generation of physical forces which could damage the capacitor elements. Such forces are often generated by the dimensional differences resulting from the normal physical tolerances of the components.

The capacitor elements must not be used as a mechanical support for other devices or components. For further mounting guidelines see the individual datasheets.

SOLDERING RECOMMENDATIONS (CAPACITORS WITH LEADS)

Mounting of the component should be achieved using Sn 60/40 or silver bearing Sn 62/36/2 Ag solder, whereby solder wire, cream, or preforms are acceptable. Only a mildly active, resin flux should be used.

We recommend the use of a heat sink adjacent to the component body, if possible.

As ceramic capacitors are very sensitive to rapid changes in temperature (thermal shock), a pre-heat and post-heat cycle is strongly recommended.

Both the component and ground plate should be heated up to 120 °C (heat must not be applied directly to the ceramic body and the temperature on the component surface should not be allowed to increase faster than 100 °C per minute).

After the pre-heat cycle, the mounting plate temperature should be raised to achieve solder flow. The solder flow state should be maintained for a minimum period (recommendation: less than 5 s) and the tip temperature should be maintained for a minimum period (recommendation: less than 5 s) and the tip temperature should be as low as possible (max. 260 °C).

The assembly should be allowed to cool at a rate not exceeding 100 °C per minute.

SOLDERING SPECIFICATIONS		
Soldering test for capacitors with wire leads: (according to IEC 60068-2-20, solder bath method)		
	SOLDERABILITY	RESISTANCE TO SOLDERING HEAT
Soldering temperature	(235 ± 5) °C	(260 ± 5) °C
Soldering duration	(2 ± 0.5) s	(10 ± 1) s
Distance from component body	≥ 2 mm	≥ 5 mm

CLEANING

The components should be cleaned with vapor degreasers, immediately following the soldering operation.

CERAMIC MATERIALS

Ceramic dielectrics are inorganic materials, sintered at temperatures above 1000 °C, and developed especially for the manufacture of capacitors.

Ceramic RF power capacitors are subdivided into two classes, in accordance with recommendations of IEC (International Electrotechnical Commission) with respect to the chemical composition of the dielectric and electrical characteristics.

Class 1 or low-K (NDK) are mainly manufactured of titanium dioxide or magnesium silicate.

Class 2 or high-K capacitors (HDK) contain mostly alkaline earth titanates.

Listed in the tables below are general physical and electrical characteristics of the ceramic dielectric used.

CLASS 1 CERAMIC MATERIALS

ABBREVIATION FOR DIELECTRIC	RELATIVE DIELECTRIC CONSTANT ($\in_r$)	CERAMIC TYPE ACCORDING TO IEC 60672-3	TEMPERATURE COEFFICIENT OF THE CAPACITANCE (10^{-6}/K)	DISSIPATION FACTOR (10^{-3})	INSULATION RESISTANCE (Ω)	PERMISSIBLE TEMPERATURE RANGE (°C)	MAX. RELATIVE AIR HUMIDITY (%)
R 7	~ 7	C 221	+130 +70	≤ 0.5 (1 MHz)	≥ 10^{10}	-55 to +100	75 %
R 16	~ 16	C 320	+130 +70	≤ 0.4 (1 MHz)	≥ 10^{10}	-55 to +100	75 %
R 16 HIGH Q	~ 17	C 320	+115 +85	≤ 0.15 (1 MHz)	≥ 10^{11}	-55 to +100	75 %
NP 0	~ 32	C 320	-30 +30	≤ 5 (1 MHz)	≥ 10^{10}	-55 to +85	75 %
R 42	~ 40	C 331	-200 -300	≤ 0.5 (1 MHz)	≥ 10^{10}	-55 to +100	75 %
R 85 (N 750)	~ 90	C 310	-650 -850	≤ 0.5 (1 MHz)	≥ 10^{10}	-55 to +100	75 %
R 230	~ 230	C 340	-750 -1000	≤ 0.5 (1 MHz)	≥ 10^{10}	-25 to +100	75 %
N 2200	~ 225	C 340	-1700 -2700	≤ 1.5 (1 MHz)	≥ 10^{10}	-55 to +100	75 %
N 3300	~ 310	C 340	-2800 -3800	≤ 2 (1 MHz)	≥ 10^{10}	-25 to +85	75 %
N 5600	~ 475	C 340	-4600 -6600	≤ 2 (1 MHz)	≥ 10^{10}	-25 to +85	75 %

CLASS 2 CERAMIC MATERIALS							
ABBREVIATION FOR DIELECTRIC	RELATIVE DIELECTRIC CONSTANT (ϵ_r)	CERAMIC TYPE ACCORDING TO		DISSIPATION FACTOR (10^{-3})	INSULATION RESISTANCE (Ω)	PERMISSIBLE TEMPERATURE RANGE (°C)	MAX. RELATIVE AIR HUMIDITY (%)
		IEC 60672-3	EIA 198				
R 700	~ 720	C 350	-	≤ 25 (1 kHz)	$\geq 10^{10}$	-25 to +85	75 %
R 1400	~ 1500	C 350	-	≤ 25 (1 kHz)	$\geq 10^{10}$	-25 to +85	75 %
R 2000	~ 2200	C 351	-	≤ 25 (1 kHz)	$\geq 10^{10}$	-25 to +85	75 %
R 2000 H	~ 2200	C 351	-	≤ 5 (1 kHz)	$\geq 10^{10}$	-25 to +85	75 %
R 2005	~ 2600	C 351	-	≤ 25 (1 kHz)	$\geq 10^{10}$	-25 to +85	75 %
R 3500	~ 3600	KER 350	-	≤ 25 (1 kHz)	$\geq 5 \times 10^{9}$	-25 to +85	75 %
R 4000	~ 3800	C 351	-	≤ 25 (1 kHz)	$\geq 5 \times 10^{9}$	-25 to +85	75 %
R 6000	~ 6300	C 351	-	≤ 25 (1 kHz)	$\geq 5 \times 10^{9}$	-25 to +85	75 %
X7R	~ 4500	-	2	≤ 20 (1 kHz)	$\geq 10^{11}$	-30 to +85	-
Y5U	~ 8500	-	3	≤ 20 (1 kHz)	$\geq 10^{11}$	-30 to +85	-
Z5U	~ 5000	-	3	≤ 20 (1 kHz)	$\geq 10^{11}$	-30 to +85	-

Note

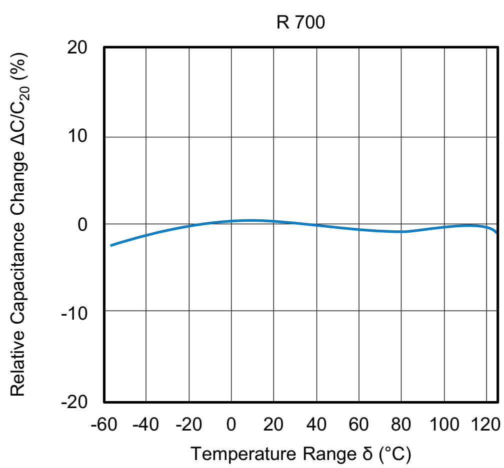
(1) For temperature dependence of capacitance for these class 2 ceramic materials see curves in section "Temperature Dependency of the Capacitance With Class 2 Capacitors"

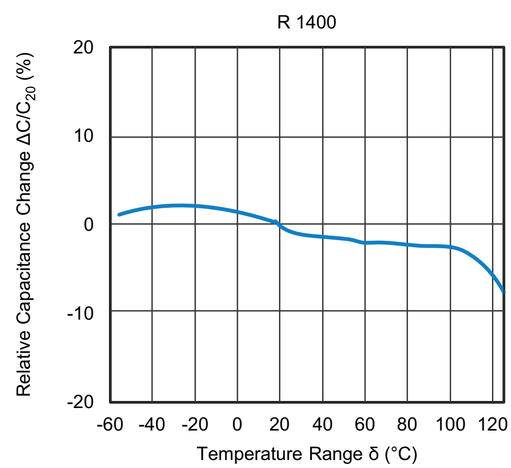
TEMPERATURE DEPENDENCY OF THE CAPACITANCE WITH CLASS 2 CAPACITORS

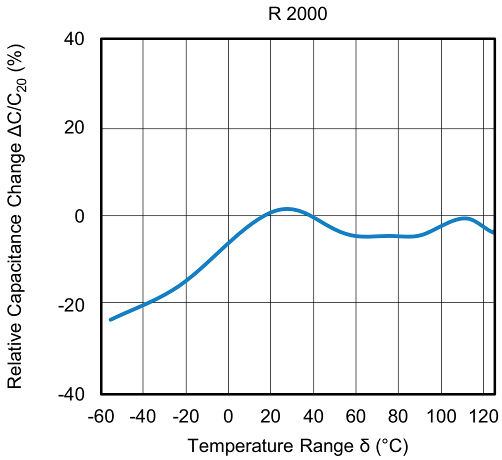
C_{20}: capacitance at 20 °C without DC

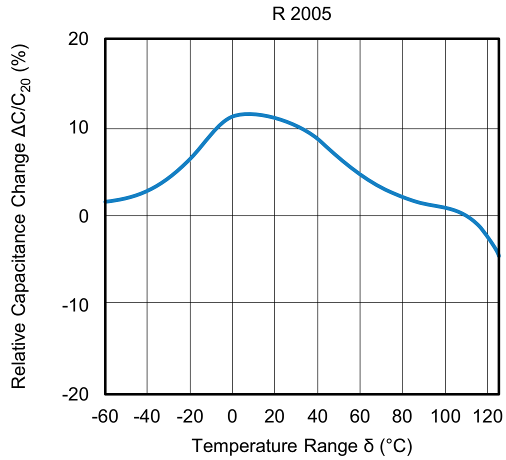
Measuring frequency: 1 kHz

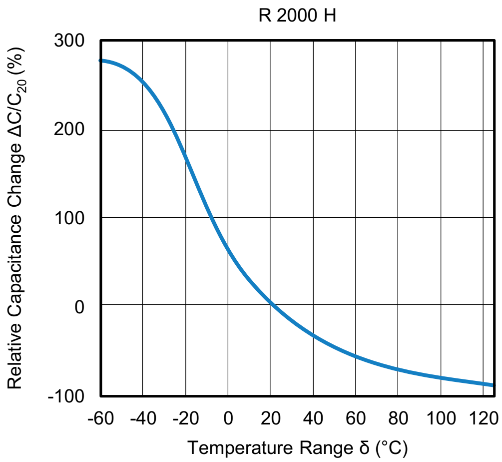
Measuring voltage: ≤ 1.2 V_{RMS}

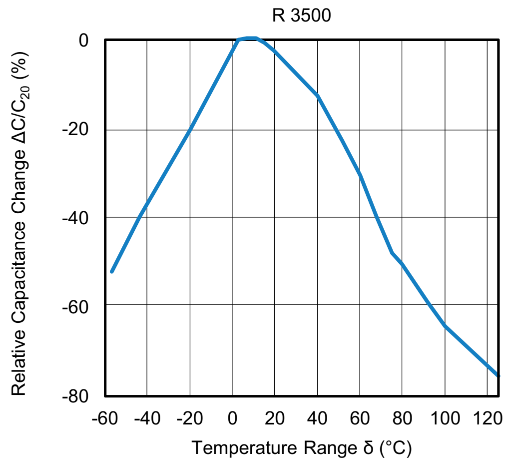


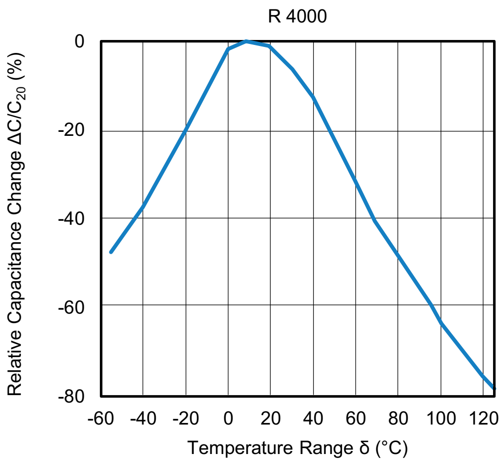


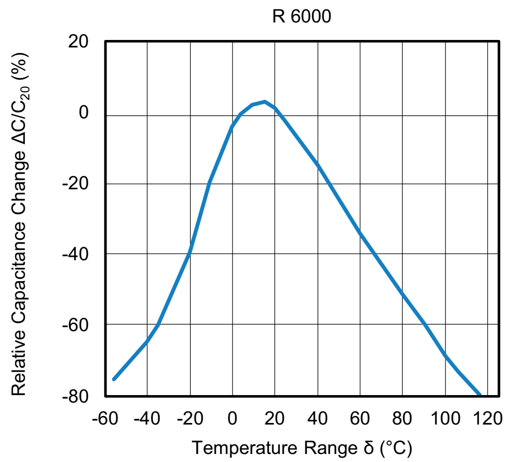

R 2000
Relative Capacitance Change ΔC/C20 (%)
40
20
0
-20
-40
-60 -40 -20 0 20 40 60 80 100 120
Temperature Range δ (°C)

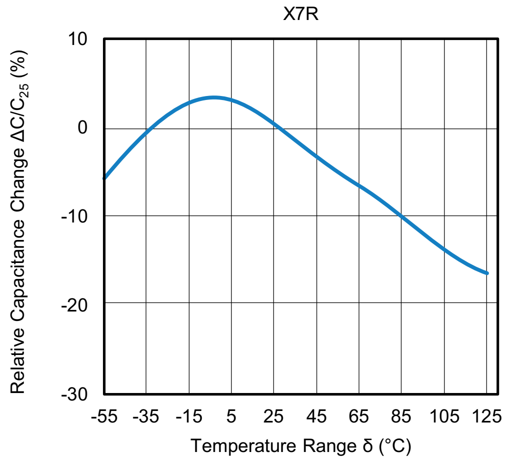

R 2005
Relative Capacitance Change ΔC/C20 (%)
20
10
0
-10
-20
-60 -40 -20 0 20 40 60 80 100 120
Temperature Range δ (°C)

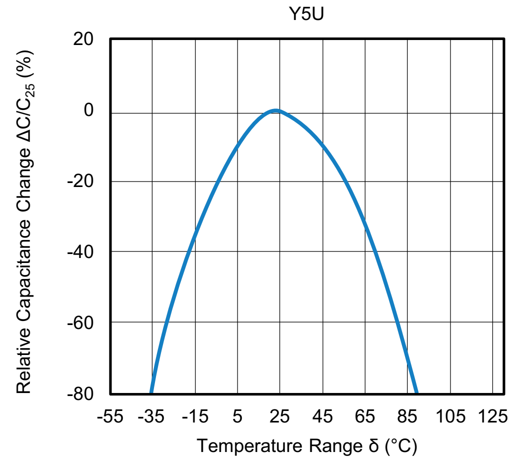

R 2000 H
Relative Capacitance Change ΔC/C20 (%)
300
200
100
0
-100
-60 -40 -20 0 20 40 60 80 100 120
Temperature Range δ (°C)

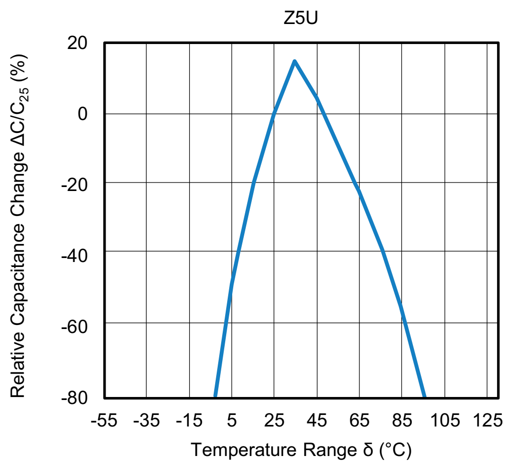

R 3500
Relative Capacitance Change ΔC/C20 (%)
0
-20
-40
-60
-80
-60 -40 -20 0 20 40 60 80 100 120
Temperature Range δ (°C)


R 4000
Relative Capacitance Change ΔC/C20 (%)
0
-20
-40
-60
-80
-60 -40 -20 0 20 40 60 80 100 120
Temperature Range δ (°C)


R 6000
Relative Capacitance Change ΔC/C20 (%)
20
0
-20
-40
-60
-80
-60 -40 -20 0 20 40 60 80 100 120
Temperature Range δ (°C)

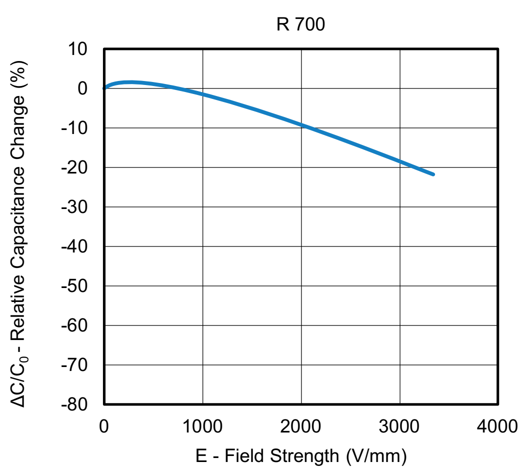


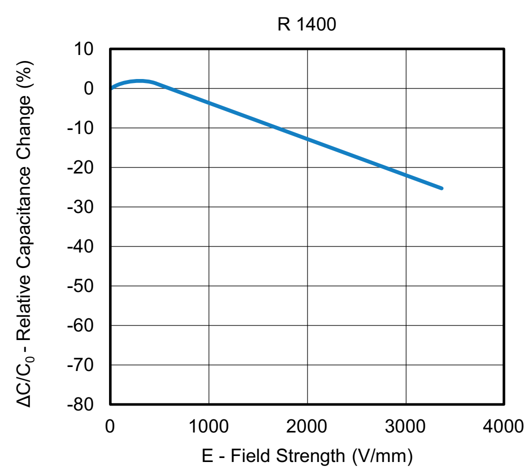




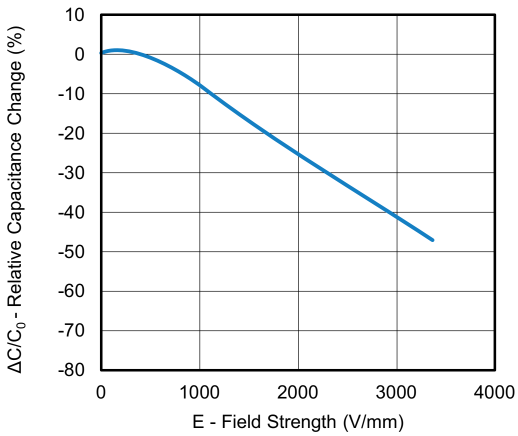
DC VOLTAGE DEPENDENCY OF CAPACITANCE (TYPICAL VALUES)

The capacitance of class 1 capacitors scarcely changes when DC voltage is applied.
The relative capacitance change of class 2 ceramic dielectric vs. applied field strength is given in the curves below.

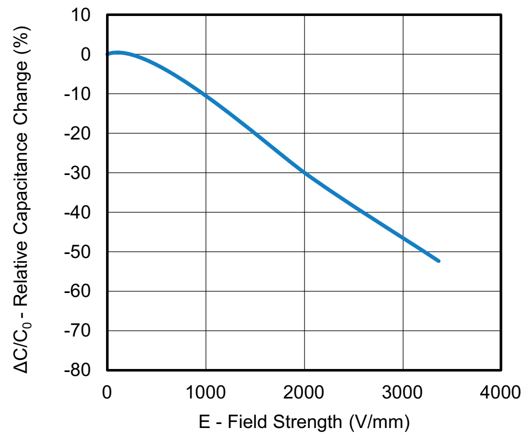




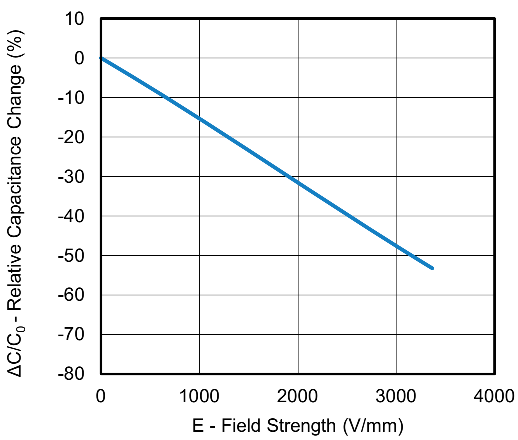
R 2000



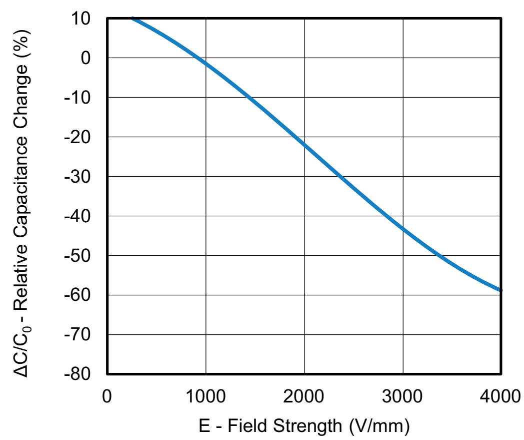
R 2005



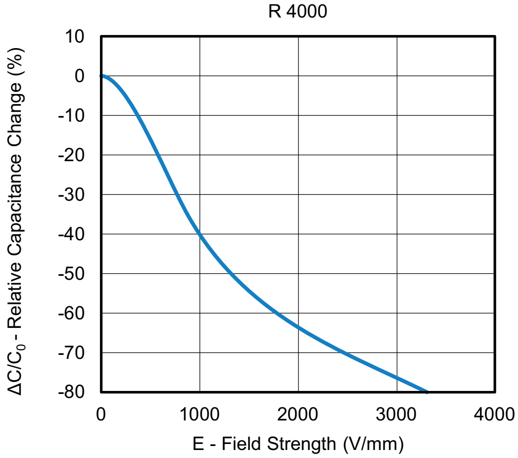
R 2000H



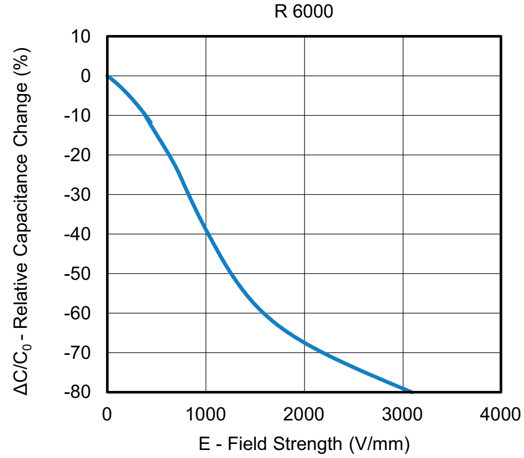
R 3500



R 4000



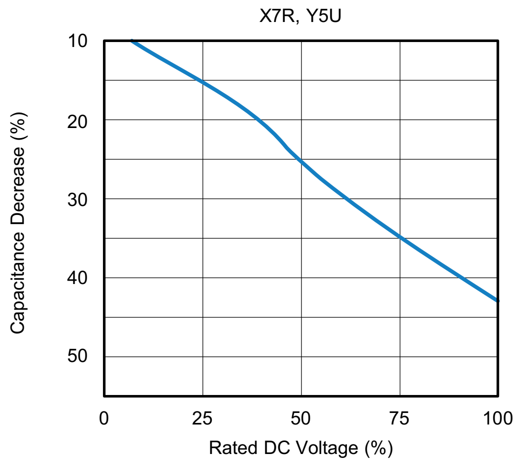
R 6000

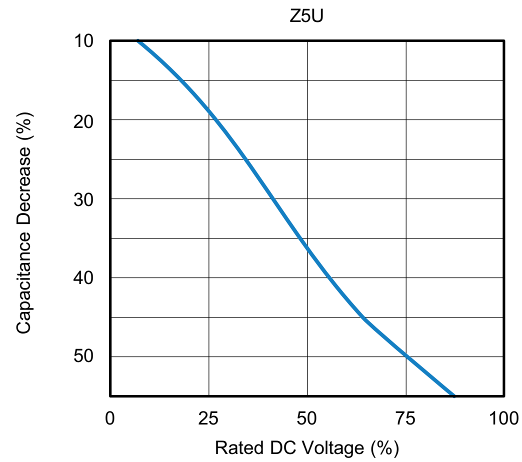


Note

- C_0: capacitance without DC voltage measuring frequency: 1 kHz
  Temperature of measurement: 23 °C ± 3 °C
  Measuring voltage: ≤ 1.2 V_{RMS}

CAPACITANCE DECREASE VS. DC VOLTAGE BIAS





QUALITY CONTROL AND TESTING

The quality of our RF power capacitors is assured by numerous tests carried out at every stage of production. The finished capacitors are subjected to the individual 100 % tests given below.

CAPACITANCE

Class 1 ceramics at 0.1 MHz, with 20 V_{RMS}, (25 ± 5) °C
Class 2 ceramics at 1 kHz, with ≤ 5 V_{RMS}, (25 ± 5) °C

DISSIPATION FACTOR

Class 1 ceramics (C_R < 1000 pF) at 1 MHz, with 10 V_{RMS}, (25 ± 5) °C
Class 1 ceramics (C_R ≥ 1000 pF) at 300 kHz, with 10 V_{RMS}, (25 ± 5) °C
Class 2 ceramics at 1 kHz, with ≤ 5 V_{RMS}, (25 ± 5) °C

INSULATION RESISTANCE

At 100 V_{DC}, (25 ± 5) °C

DIELECTRIC WITHSTANDING

Standard test with 200 % U_R, AC 50 Hz, 5 min. (as repeated test admissible only once with a step-up voltage reduced by 10 % for 3 min).

RF HEATING TEST

This 100 % test is carried out with water cooled pot capacitors, multilayer power capacitors and those components made from R 230 dielectric only.

The units are tested in the tank circuit of a RF test generator with at least 130 % to 150 % rated power for 5 min to 10 min.

For all other types, this RF power test is subject to special agreement.

For details of water cooled capacitors see individual datasheets.

VISUAL CONTROL AND DIMENSIONS OUTLINE DRAWINGS

All dimensions are given in millimeters and inches (in brackets).

As a result of continual efforts to improve mechanical design, components supplied may vary in detail from those described or illustrated in the outline drawings of this catalog.

STANDARDS AND SPECIFICATIONS	
GENERAL STANDARDS	
IEC 60062	Marking codes for resistors and capacitors
IEC 60068	Basic environmental testing procedures
SPECIAL STANDARDS FOR CERAMIC CAPACITORS	
EN 130600 and IEC 60384-8	Fixed capacitors of ceramic dielectric, class 1
EN 130700 and IEC 60384-9	Fixed capacitors of ceramic dielectric, class 2